

MODELLING AND SIMULATION OF THE GRINDING CIRCUIT AT 'EL PILON' MINE

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Abstract

The grinding operation in a ball mill is widely used in comminution. This process is extremely capital and energy intensive process and at the same time it is notoriously inefficient. Therefore, simulation can be used as a convenient tool in studying the behaviour and performance of grinding circuits by facilitating the evaluation of various scenarios and identification of optimum operating conditions. This paper presents how these modern simulation techniques are applicable to a grinding circuit using JKSimMet computer package.

A grinding model developed at 'El Pilon' mine using JKSimMet (Version 4) was used to simulate three different milling designs. The objective of these simulations was to investigate a new design of the grinding circuit with an additional ball mill to increase both grinding throughput and fineness. The simulation results highlight that two closed grinding circuits in series are more appropriate to achieve these targets. Surveying the implemented grinding circuit validated the JKSimMet simulation results. An increase of grinding throughput from 600 tpd to 800 tpd was achieved in the grinding circuit in serie as well as an increase of the grinding fineness from 57% to 75% passing 75 μm .

This case study shows that JKSimMet can be used to design grinding circuit accuracy and highlights that this computer simulator is a powerful tool in the optimisation of comminution circuits.

Key words: Grinding circuit; milling in serie; modelling; optimisation; simulation

INTRODUCTION

The grinding operation in a ball mill is widely used in comminution. However, this process is extremely capital and energy intensive process and at the same time it is notoriously inefficient. Therefore, accurate designing of both circuit and operating parameters are important to optimise the power consumption, which can lead to substantial economic benefit. Simulation can be used as a convenient tool in studying the behaviour and performance of grinding circuits by facilitating the evaluation of various scenarios and identification of optimum operating conditions. Currently, the development of simulators for mineral

processing units has considerably increased in last decade; e.g. typical software packages are USIM PAC (Broussand et al, 1988), JKSimMet (JKTech, 1989), MODSIM (Herbst et al, 1989), and SIMBAL (CANMET, 1989).

JKSimMet (Version 4) computer package is used in this study to model and simulate the 'El Pilon' grinding and classification stages. This simulator was used to assist in the design of a new grinding circuit with the addition of a new ball mill in order to increase both grinding throughput and fineness. Thus, simulation results are implemented in the plant which were validated with a new sampling campaign.

'EL PILON' MINE

'El Pilon' mine mill is located in the town of San Martin de Bolaños, approximately 500 km east of the Guadalajara State in Northern Mexico. The concentrator processes a sulphide orebody consisting of 1.64% Pb, 0.10% Cu, 5.31% Fe and 2.64% Zn. Silver content ranges from 270 to 320 g/ton and gold from 0.20 to 0.34 g/ton. The ore is leached with cyanide to obtain the doré (i.e. Ag-Au alloy). Current milling rates are approximately 600 ton/day (tpd).

Ore is delivered to the mill by trucks and sent directly to the primary crusher. The ore is crushed in a primary jaw crusher and transported by conveyor to the secondary and tertiary crushing circuit. The crushing circuit product contains material approximately 96% passing 9.53 mm (3/8 inches). This material is conveyed via belt feeders to the 2.59-m by 3.67-m (8 ft ½ inches in diameter by 12.0 ft in length) 300 HP Marcy ball mill. The ball mill, with 40% of mill filling and 70% of its critical speed, is fitted with steel liners. It uses steel balls in a ratio of 70% of 76.2 mm (3 inches) and 30% of 50.8 mm (2 inches) as grinding media. The pulp density in the ball mill is maintained at 76% solids, and lime and cyanide are added to the mill feed. Lime addition increases the circuit pH to reduce volatilization of cyanide and to increase the settling of material in the thickener downstream. Cyanide is used to leach silver/gold bearing particles throughout the circuit.

The grinding circuit uses a two-stage cyclone process to classify mill discharge. The classification circuit consists of two 0.508-m (20 inches) diameter cyclone. Only one cyclone is operating at a time while the other is on stand-by. Discharge from the ball mill flows to a pump box where it is diluted to a density approximately 48% solids before being sent to the cyclone, for classification, by means of a 0.20 m by 0.15 m (DRL 8 inches by 6 inches) pump at 870 rpm. Underflow from the cyclone is fed back to the ball mill while the overflow material (19% to 22% solid) with 58% passing 75 µm (200 mesh) is directed to a 19.81 m (65 foot) diameter thickener located outside the east wall of the mill complex. Underflow of the thickener, having a pulp density from 50 to 60% solids, is sent to the leaching process. The leached pulp and its silver/gold bearing solution are treated using the Merrill Crowe process to obtain the doré.

GRINDING CIRCUIT SIMULATOR

JKSimMet is a powerful tool for analysis and simulation of mineral processing plant data. It gives engineers the ability to design and optimise any crushing or grinding circuit including stages of classification. It allows engineers to:

- Design a circuit on the graphics monitor,
- Enter model and plant data,
- Simulate the circuit, and
- Graph and print the results.

JKSimMet performs steady state simulation of a range of comminution and classification operations. The principal application of JKSimMet is to carry out process analysis and optimisation of existing circuits and also extremely useful for conducting conceptual design studies, where the purpose is to assess the suitability of different flowsheets to achieve a desired performance objective, as presented in this paper.

Mathematical Models

Process models of the two main units at 'El Pilon' grinding circuit are presented:

- Ball mill, and
- Hydrocyclone

Ball Mill

The perfect mixed model (Whiten, 1976) is quite similar to the general population balance model. This model assumes a perfectly mixed mill which removes most of the complexities in the general population balance model. The perfect mixed model start with the same population balance, i.e.

$$\text{Feed in} + \text{Breakage in} = \text{Product out} + \text{Breakage out} \quad (1)$$

However, two factors control the breakage of particles inside the mill as follows:

- Selection function which defines the breakage probability of particles,

$$p_i = d_i s_i \quad (2)$$

where, d_i , is the discharge function in the mill, thus

$$\text{selection} = r_i s_i \quad (\text{breakage out}) \quad (3)$$

Breakage function which define how the selected particles are broken (appearance function) in the mill content:

$$\text{appearance} = a_{ij}r_js_j \quad (\text{breakage in}) \quad (4)$$

Then, the balance equation around each size fraction, which describes the mill behaviour, is:

$$f_i + \sum_{j=1}^i a_{ij}r_js_j = p_i + r_is_i \quad (5)$$

Now substitute for the experimentally mill contents:

$$f_i + \sum_{j=1}^i \left[\frac{a_{ij}r_jp_j}{d_j} \right] = p_i + r_i \frac{p_i}{d_i} \quad (6)$$

This means that the ratio $\frac{r_i}{d_i}$ can be calculated for each size fraction from a set of actual feed (f_i) and product (p_i) measurements, subject to a reasonable form of the appearance function (a_{ij}).

Hydrocyclone

The hydrocyclone model used in this study was that developed by Nageswararao under the supervision of A. J. Lynch and L. Elber (Nageswararao, 1978). This model comprises empirical equations for the main performance criteria, incorporating terms suggested by dimensional reasoning with exponents estimated from data sets obtained by Nageswararao (1978) and Rao (Lynch and Rao, 1975). The predictive equations are:

$$\frac{d_{50c}}{D_c} = K_{D1} \left(\frac{D_o}{D_c} \right)^{0.52} \left(\frac{D_u}{D_c} \right)^{-0.47} \lambda^{0.93} \left(\frac{P}{\rho_p g D_c} \right)^{-0.22} \left(\frac{D_i}{D_c} \right)^{-0.50} \left(\frac{L_c}{D_c} \right)^{0.20} \theta^{0.15} \quad (7)$$

and

$$K_{D1} = K_{D0} D_c^{-0.65} \quad (8)$$

where K_{D0} depends on feed solids characteristics only.

$$Q_f = K_{Q1} D_c^2 \left(\frac{P}{\rho_p} \right)^{0.50} \left(\frac{D_o}{D_c} \right)^{0.68} \left(\frac{D_i}{D_c} \right)^{0.45} \theta^{-0.1} \left(\frac{L_c}{D_c} \right)^{0.20} \quad (9)$$

For cyclones of Krebs geometry treating identical feeds:

$$K_{Q1} = K_{Q0} D_C^{-0.10} \quad (10)$$

where K_{Q0} depends on feed solids characteristics only.

$$R_f = K_{W1} \left(\frac{D_O}{D_C} \right)^{-1.19} \left(\frac{D_U}{D_C} \right)^{2.40} \left(\frac{P}{\rho_p g D_C} \right)^{-0.53} \lambda^{0.27} \left(\frac{D_i}{D_C} \right)^{-0.50} \theta^{-0.24} \left(\frac{L_C}{D_C} \right)^{0.22} \quad (11)$$

$$R_v = K_{V1} \left(\frac{D_O}{D_C} \right)^{-0.94} \left(\frac{D_U}{D_C} \right)^{1.83} \left(\frac{P}{\rho_p g D_C} \right)^{-0.31} \left(\frac{D_i}{D_C} \right)^{-0.25} \theta^{-0.24} \left(\frac{L_C}{D_C} \right)^{0.22} \quad (12)$$

where D_i is inlet diameter (diameter of circle of some area as cyclone inlet), m

D_O is overflow (vortex finder) diameter, m

D_U is underflow (apex) diameter, m

D_C is cyclone cylinder diameter, m

L_C is length of cylindrical section, m

θ is cone full angle, degrees

P is feed pressure at inlet, kPa

ρ_p is feed slurry density, t/m^3

g is acceleration due to gravity, 9.81 m/s^2

Q_f is flowrate, m^3/h

R_f is recovery of water to underflow, %

R_v is volumetric recovery of feed slurry to underflow, %

K is constant to be estimated from data

λ is hindered settling correction term, $\frac{C_v}{(1 - C_v)^3}$

C_v is volumetric fraction of solid in feed slurry

The d_{50c} predicted by Equation 7 is inserted in the Whiten function to determine the corrected efficiency curve for the cyclone:

$$E_{oa} = C \left[\frac{(1 + \beta \beta^* x)(\exp(\alpha) - 1)}{\exp(\alpha \beta^* x) + \exp(\alpha) - 2} \right] \quad (13)$$

where α is an efficiency parameter

β is a fish-hook factor

C is recovery of water to overflow, ($C = 100 - R_f$), %

EXPERIMENTAL WORK

Metallurgical Sampling

In August 1998, two metallurgical sampling were conducted at 'El Pilon' grinding circuit (Figure 1) assuring steady state at least two hours prior surveys. The surveys were conducted under normal operations.

As illustrated in Figure 1, the sampling points in each survey were:

- New circuit feed,
- Ball mill discharge,
- Cyclone underflow, and
- Cyclone overflow.

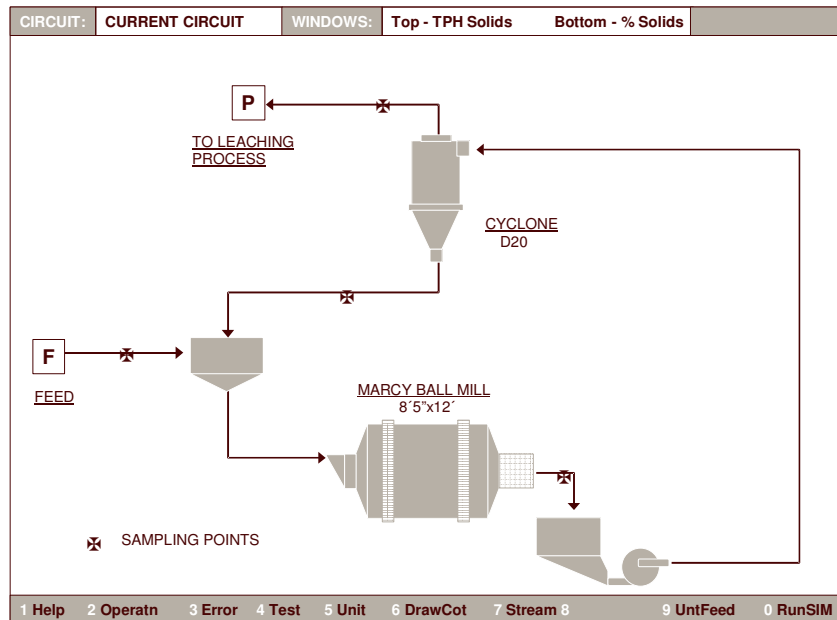


Figure 1 – Current grinding circuit at 'El Pilon' mine

Samples were cut at each of these sampling point every 15 minutes for two hours and then combined into an overall sample for sieve analysis and solid content measurements. The tonnage in the new feed stream was also recorded during each survey. Samples were weighed, dried and weighed again to calculate the percent of solids. The percent of solid was then calculated by:

$$\% \text{solid} = \frac{W_{t_s}}{W_t} * 100 \quad (14)$$

where W_{t_s} is the weight of solids, and
 W_t is the weight of slurry.

All the samples from the survey were then sized at 'El Pilon' Chemical Laboratory. Each sample was wet sieved at 45µm to remove any ultrafine particles. The +45µm material was then dry screened at 12500µm, 9520µm, 2000µm, 1700µm, 250µm, 180µm, 150µm, 106µm, 75µm, and 45µm.

RESULTS AND DISCUSSION

The results are presented and discussed into four parts (a) mass balancing, (b) model fitting, (c) simulation and (d) validation and operation of the new grinding circuit at 'El Pilon' mine.

Mass Balancing

Mass balancing is the most useful method of data assessment. JKSimMet mass balancing sub-system is used to assess data efficiently. The balancing process produces best-fit estimates of flowrates and a set of adjusted size which is consistent with those flowrates. Overall, JKSimMet mass balancing technique minimises the sum of weighed squared errors (JKTech 1989), that is:

$$SSQ = \sum_{j=1}^N \sum_{i=1}^L \left(\frac{X_{ij} - x_{ij}}{\sigma_{ij}} \right)^2 + \sum_{i=1}^L \left(\frac{A_i - a_i}{\sigma_i} \right)^2 \quad (15)$$

where N is the number of measurements,

L is the number of streams,

X is a measurement,

x is the adjusted measurement,

A is the measured flow,

a is the adjusted flow, and

σ_{ij} and σ_i are the weights or standard deviations for the measurements and flows respectively.

Based on experimental results and personal judgement, the standard deviations are assigned to the data as follows:

- For fractions greater than 10%, a standard deviation of 1.0% is assumed.
- For fractions less than 1%, a standard deviation of 0.1% is assumed.
- For fractions between 1% and 10%, a standard deviation of 0.1% plus one tenth of the fraction is assumed.

To mass balance the grinding circuit data, the new circuit feed is assumed to be accurate (i.e. contain zero error). It should be noted that the mass balancing program tells how the experimental data (including both the stream data and sizing data) meet the mass conservation criterion. It does not tell which data are accurate or inaccurate. Neither can it give the true values. The accuracy of the experimental data depends entirely on the experimental design and handling.

Based on the criterion described above, the adjusted data were very similar to the experimental values. The mass balancing results are presented in Figure 2 and the grinding performance is summarised in Table 1.

During the survey, the milling operation was observed to have a very poor performance. Under the conditions of the survey, a large recycle load in the mill 697.4% is found and also the volume percent solids in the ball mill discharge too high 52.7%. These numbers confirm the observation why a large amount of coarse particles were rejected at the end of the mill. Using the Bond power model (Eq. 16), the power draw for the mill is calculated to be 281.24 HP under the conditions of the survey. It should be noted that the power draw is 6.3% lower than the installed maximum (300 HP) while a reasonable safety margin for normal plant fluctuations may be 10%.

$$\text{Power} = W_i \cdot \left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}} \right) \cdot \text{Mill feed rate}_{\text{tph}} \quad (16)$$

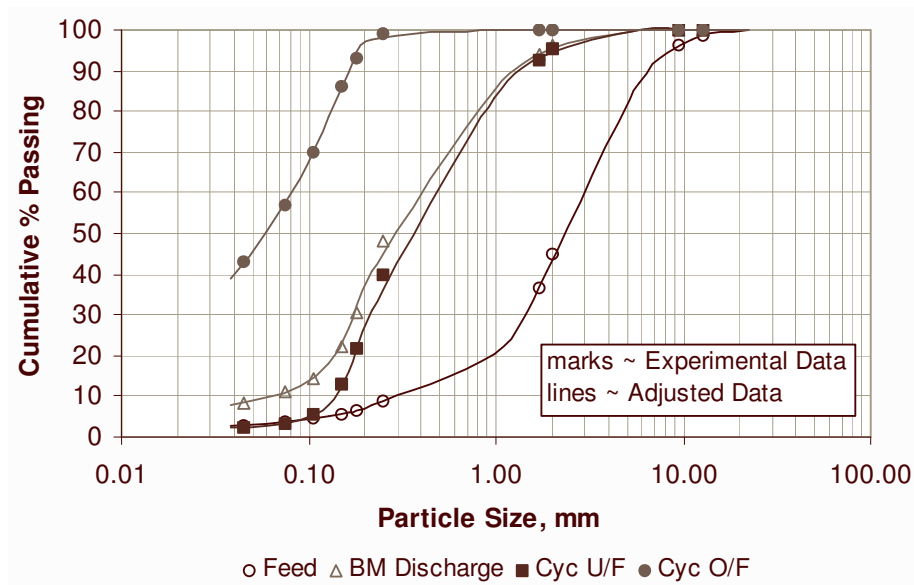


Figure 2 – Mass balancing of the grinding circuit at 'El Pilon' mine

Table 1 – Grinding circuit performance at 'El Pilon' mine (August 1998)

Stream	Solids		Water	SG Pulp	V Flowrate	% Passing 75µm
New Circuit Feed	24.95	96.5	0.91	2.63	9.81	3.50
Ball Mill Discharge	173.99	75.6	56.16	1.95	118.30	11.09
Cyclone Underflow	149.04	73.7	53.19	1.90	106.42	3.40
Cyclone Overflow	24.95	19.0	106.36	1.14	115.27	57.00
Units	[ton/h]	[%]	[ton/h]	[ton/m ³]	[m ³ /h]	[%]

Model Fitting

The mass balanced data were used to calibrate the mathematical models of ball mill and cyclone included in the JKSimMet (Version 4) simulator. It is important to know the structure of the models and what parameters have to be fitted. These subjects are presented in details in the JKSimMet manual (JKTech, 1989). The ore parameters should be determined from ore characterisation tests of representative samples. Because the main objective of this study is simulation and the ore characterisation tests was not available, the standard appearance function was chosen. Thus, the machine parameters (e.g. breakage rates) are calculated from survey data.

No significant differences were found in the calibration of 'El Pilon' models. Thus, the ball mill and cyclone parameters are assumed to represent the grinding circuit within a 30% error. Once the models have been calibrated to 'El Pilon' grinding circuit, the behaviour of the circuit over a wide range of operational conditions and designs can be predicted.

Simulation

The calibrated models were used to simulate three different flowsheets by addition of a new ball mill 9x9 ft, as described below. The new ball mill operating data are not available; however, it can be assumed that the 8.5x12-ft mill parameters can be used in the new ball mill because of the same ore treated. Overall, the simulations described below were performed at two new feed rates 700 tpd (29.2 tph) and 800 tpd (33.3 tph) and large circulating loads keeping constant the percent solid (19.0%) in the final grinding product as required by the metallurgical staff of 'El Pilon' mine. Therefore, the ball mill and cyclone design parameters (e.g. %solids, vortex, apex, etc.) were adjusted to achieve the objectives of this study - an increase in grinding throughput and fineness. Because ball mills are of the overflow discharge type, each simulation was performed considering the volume percent solid not exceed 52% to avoid the slurry transport problems.

Grinding Circuit in Parallel

Figure 3 shows the simulated circuit in which the two mills are operating in parallel each one with a classification stage in closed circuit.

The simulation results are presented in Table 2 which highlight that this design in parallel increases the grinding throughput. However, the particle size in the final product (% passing 75µm) increases only 8% and it decreases 1% as increasing the grinding throughput from 700 tpd to 800 tpd.

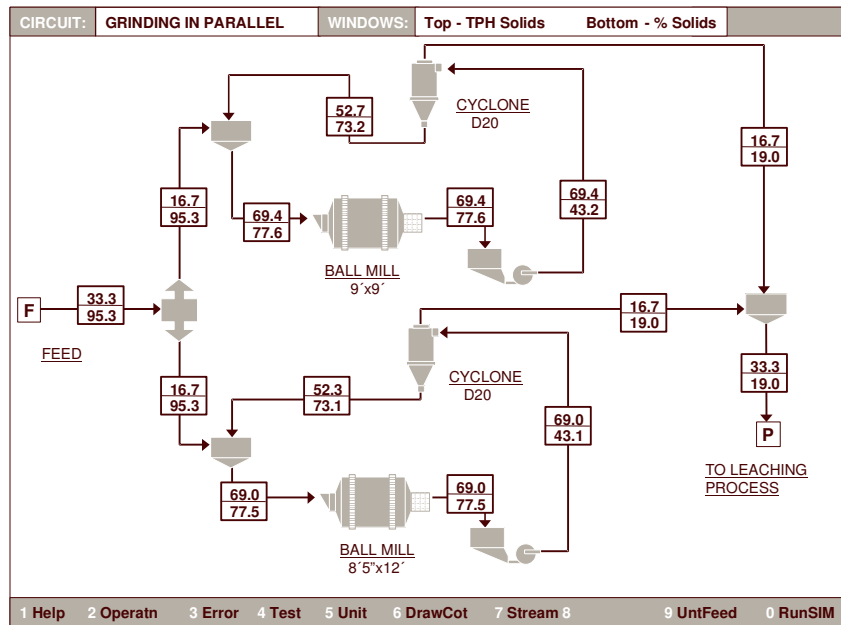


Figure 3 – Simulated grinding circuit in parallel at 'El Pilon' mine

Table 2 – Simulation results of the grinding circuit in parallel

Stream	700 tpd			800 tpd		
	Solid Flow Rate, tph	%Solids	% Passing 75 μ m	Solid Flow Rate, tph	%Solids	% Passing 75 μ m
Ball Mill 8.5x12 Circuit						
BM Discharge	58.9	74.2	23.52	69.0	77.5	21.94
Cyclone Overflow	14.6	19.0	67.01	16.9	19.0	66.05
Ball Mill 9x9 Circuit						
BM Discharge	59.2	74.3	23.32	69.4	77.6	21.75
Cyclone Overflow	14.6	19.0	66.82	16.8	19.0	65.85

Grinding Circuit in Semi-Serie

This simulated flowsheet is named 'semi-serie' because the first mill (8.5x12 ft) is operating in open circuit following by a classification stage and the second mill in inverse closed circuit with classification, as illustrated in Figure 4.

The ball mill discharge is fed into a first classification stage (cyclone D20) which the underflow is mixed with the second cyclone underflow and fed into the second mill (9x9 ft). The 9x9-mill discharge is sent into a secondary classification stage (cyclone D20). Then, the two cyclone overflows are sent to the leaching process.

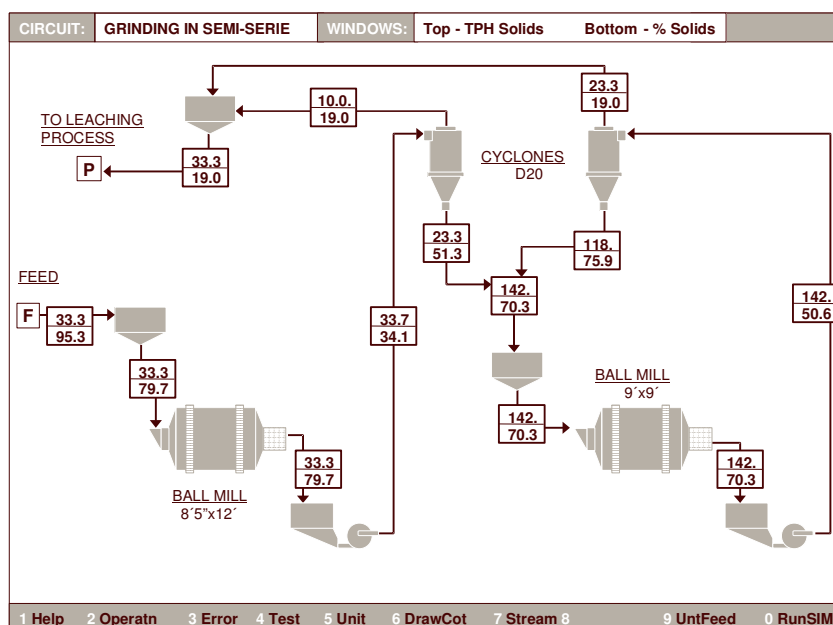


Figure 4 – Simulated grinding circuit in semi-serie at 'El Pilon' mine

Simulation results of this design are presented in Table 3. As may be seen, the solid flow rate in the first cyclone overflow is too low. The simulator predicts a very low operating pressure in this cyclone 5.34 kPa at 700 tpd and 6.57 kPa at 800 tpd. Under these conditions, the first cyclone is operating as a simple splitter increasing the final particle size in the cyclone overflow.

Table 3 – Simulation results of the grinding circuit in semi-serie

Stream	700 tpd			800 tpd		
	Solid Flow Rate, tph	%Solids	% Passing 75µm	Solid Flow Rate, tph	%Solids	% Passing 75µm
Ball Mill 8.5x12 Circuit						
BM Discharge	29.2	79.7	38.92	33.3	79.7	36.63
Cyclone Overflow	8.7	19.0	76.94	10.0	19.0	76.41
Ball Mill 9x9 Circuit						
BM Discharge	109.0	63.3	20.25	142.0	70.3	13.85
Cyclone Overflow	20.5	19.0	66.64	23.3	19.0	56.55

However, the particle size in the second cyclone overflow is coarse 66.6% passing 75µm at 700 tpd and 56.6% at 800 tpd. Overall, the particle size in the final grinding product is affected by the performance of the second cyclone. These results were achieved using a top ball size of 70% at 76.2mm and 30% at 50.8 mm in both mills. Subsequent simulations were conducted by decreasing the top ball size (100% at 50.8 mm) in the second mill however 4.7 tph (112.8 tpd) of 2mm particles (> 2000µm) remains without being breakage.

Table 4 – Simulation results of the grinding circuit in serie

Stream	700 tpd			800 tpd		
	Solid Flow Rate, tph	%Solids	% Passing 75µm	Solid Flow Rate, tph	%Solids	% Passing 75µm
Ball Mill 8.5x12 Circuit						
BM Discharge	182.0	79.7	13.0	216.0	80.0	11.4
Cyclone Overflow	29.2	19.0	56.6	33.3	19.0	53.9
Ball Mill 9x9 Circuit						
BM Discharge	63.8	76.1	20.6	82.5	79.9	17.8
Cyclone Overflow	29.2	19.0	76.0	33.3	19.0	74.3

Selection of the New Grinding Design

The grinding circuit in serie showed the best performance as presented in Table 5. The proposed flowsheet achieves the objectives of 'El Pilon' mine by increasing both grinding throughput and fineness. This flowsheet increases the grinding throughput from 600 tpd to 700 tpd and increases the particle size in the final product from 57% to 75% passing 75µm.

Table 5 – Evaluation of the simulated flowsheets at 'El Pilon' mine

Simulated Flowsheets	Objectives of 'El Pilon' mine	
	Grinding Throughput	% Passing 75µm
Grinding in Serie	↑	↑
Grinding in Semi-Serie	↑	↓
Grinding in Parallel	↑	Without change

The grinding circuit in serie shows the following advantages compared with the other two simulated flowsheets:

- It is possible to increase the grinding throughput without affecting the particle size in the final product,
- The second mill can be operated with small ball size, which increase the fineness of the overall grinding circuit at 'El Pilon' mine.

GRINDING CIRCUIT IN SERIE – ITS VALIDATION AND OPERATION

Based on the analysis of the simulated flowsheets, the grinding circuit in serie was implemented in the plant. New survey was conducted in the grinding circuit which was used to validate the simulation results. The new sampling showed that this circuit is milling 800 tpd and the particle size in the final product is 76% passing 75 μ m.

Figure 6 shows the predicted particle size distribution using the JKSimMet computer package and the real particle size distribution based on the survey data of the grinding circuit in operation. The new particle size distribution in the circuit feed is similar with that distribution used in the simulations.

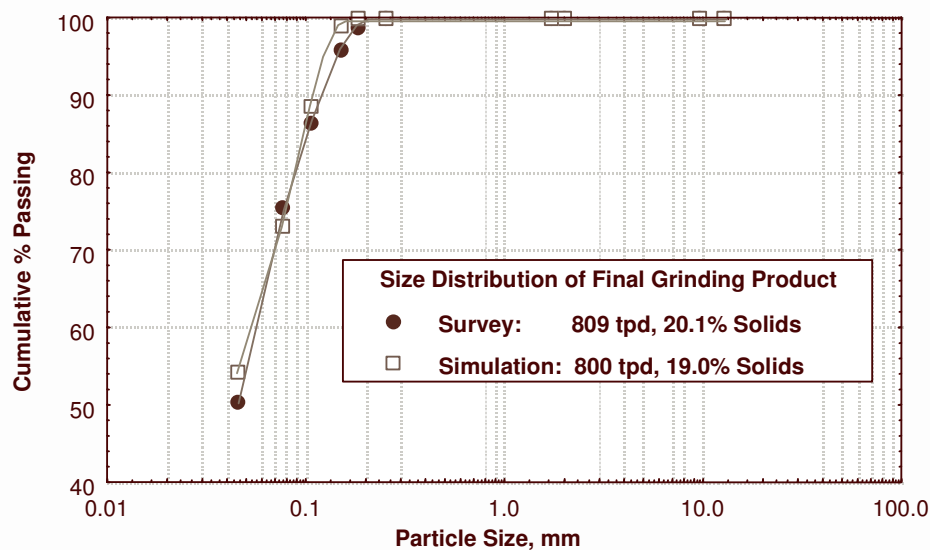


Figure 6 – Comparison of the particle size distribution of the final product in the grinding circuit in serie at 'El Pilon' mine

The real operation (survey data) and the simulated values are in 10% of confidentiality. Therefore, the JKSimMet computer simulator proves a valuable tool in the design of new grinding circuit.

Optimisation

Optimal parameters were optimised to maintain a more stable operation in the implemented grinding circuit using the JKSimMet computer simulator. The effects investigated in the optimisation exercise were; (1) ball size in the second ball mill, (2) maximum grinding throughput in the grinding circuit in serie, and (3) optimal dimensions of vortex and apex in cyclones.

The simulation results shows that the following ball size should be used in mills; 100% at 76.2mm in the first mill (8.5x12 ft) and 100% at 38.1mm in the second mill (9x9 ft). Additional simulations were conducted by changing the ball size in the second mill as presented in Figure 7.

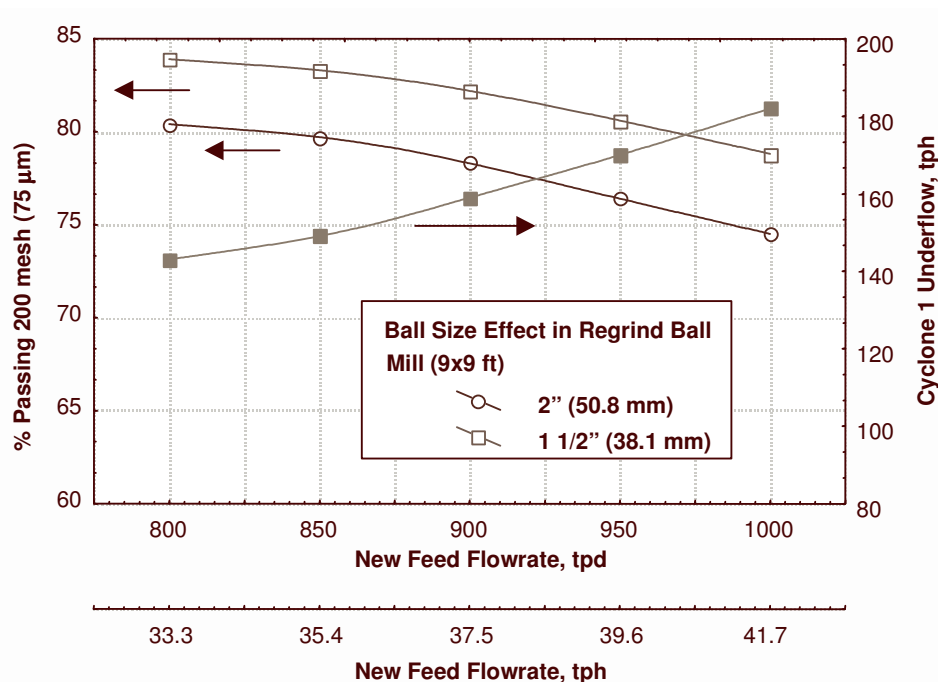


Figure 7 – Effect of ball size in the second mill of the grinding circuit in serie

As you may see in Figure 7, the ball size in the second mill has control of the particle size in the final grinding product. As expected, by increasing the grinding throughput a decrease in the particle size is observed. However, the first cyclone underflow flowrate increases as increase the grinding throughput. Again, this could be a limitation in the first ball mill performance. To avoid this effect, a large percent of solid in the cyclone feed and vortex diameter would be used instead.

By decreasing the ball size in the second mill from 50.8 mm to 38.1mm an increase of 4.0% is observed. The result highlights that the grinding circuit would be able to operate up to 1000 tpd keeping the particle size in the final product as desired. However, the maximum percent of solids in the first cyclone and the pump capacity should be investigated.

CONCLUSIONS

A grinding model developed at 'El Pilon' mine using JKSimMet (Version 4) was used to simulate three different milling designs. Simulation shows that the grinding circuit in serie has better advantages in terms of milling performance than the grinding circuit in parallel or the grinding circuit in semi-serie. An increase of grinding throughput from 600 tpd to 800 tpd was achieved by implementing a grinding circuit in serie as well as an increase of the grinding fineness from 57% to 75% passing 75μm.

This case study shows how JKSimMet can be used to design grinding circuit accuracy and highlights that this computer simulator is a powerful tool in the optimisation of comminution circuits.

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REFERENCES

- Broussand, A., Connil, P., and Fourniguet, G., 1988, "USIM: An easy to use industrial simulator for mineral processing plants", Computer Applications in the Mineral Industry, ISBN 906191 7603, Balkema Rotterdam, 137-145.
- CANMET, 1989. SIMBAL Brochure, CANMET, 552 Booth Street, Ottawa, Ontario, Canada, K1A-0G1.
- Herbst, J.A., Schena, G.D. and Fu, L.S., 1989. "Incorporating state of the art models into a mineral processing plant simulator", Trans. Instn. Min. Metall., 98, C1-C11.
- JKTech., 1989. JKSImMet User Manual and Supplementary Information Manual (Version 4, Release 1), *JKTech*, Indooroopilly, Qld., Australia.
- Lynch A.J. and Morrell S. 1992. The understanding of comminution and classification and its practical application in plant design and optimisation. *Comminution: Theory and Practice*, Ed. Kawatra, 405-426 (AIME).
- Lynch, A.J. and Rao, T.C., 1975. "Modelling and scale-up of hydrocyclone classifiers". In Proceedings XI Int Min Proc Congress, Cagliari, Paper 9.
- Nageswararao K. 1978. *Further developments in the modelling and scale up of industrial hydrocyclones*. PhD Thesis, University of Queensland (JKMRC).
- Whiten, W.J., 1976. "Ball mill simulation using small calculators". In Proceedings AusIMM, 258, 47-53.